

R & D WORK ON THE CONSTRAINED VAPOR BUBBLE SYSTEM  
FOR A MICROGRAVITY EXPERIMENT

SUMMARY OF RESEARCH (FINAL) REPORT FOR NAG3-2383  
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## **1. ABSTRACT**

We are working with Project Scientists R. Balasubramanian and Sang Young Son, and a NASA Projects Team headed by Sue Motil at the Glenn Research Center on the design and development of an experimental system for use on the International Space Station during the year 2006. John Eustace is the coordinator for the flight experiment at Zin-Tech (previously Northrop-Grumman) for the design and development of the Constrained Vapor Bubble Heat Exchanger, CVBHX, cell which will fit into the Light Microscope Module, LMM. Good progress is being made. The CDR for the LMM being developed was held on December 10-11, 2003. Experimental results obtained under microgravity conditions will be compared with those obtained at Rensselaer.

Basic and applied research at Rensselaer continues on the experimental and theoretical details associated with passive phase change heat transfer processes controlled by interfacial forces in the CVBHX. The extensive results of our current research are presented in the 23 external publications listed below. Twenty-two external presentations have been given. Briefly, evaporation/condensation data from both vertical and horizontal CVBHX systems were obtained and analyzed for both polar (wetting) and apolar (partially wetting) fluids. The vertical system is axi-symmetric, but strongly effected by gravity. Whereas, the horizontal system is asymmetric, but weakly effected by gravity. Therefore, there will be significant differences in the operation of the cell in the earth's environment versus the operation under microgravity conditions. Due to its relative large size, the system's performance should be optimum under micro-gravity conditions, where the CVBHX should be a very effective passive heat exchanger.

The CVBHX was found to be an ideal experimental setup in which to study the effects of interfacial phenomena on both the evaporation and drop-wise condensation processes. The optical technique (Image Analyzing Interferometry, IAI), which is based on the measurement and analysis of the reflectivity pattern of a thin film, was significantly improved. The accuracy of the IAI system is of critical importance to the success of the mission because it is used to measure the details of the pressure field in the liquid by measuring the film thickness profile. The accuracy was found to be excellent and various publications/presentations documenting these new results were written. Significant new results were also obtained for the effect of the oscillating contact line region on evaporation.

Three doctoral students graduated under this grant. All three work in US industry, two for Intel. Another doctoral student is in his third year of study and will finish under an extension of the NASA grant: # NNC05GA27G.

## **2. RESEARCH OBJECTIVES AND APPROACH**

The thermophysical principles underlying change-of-phase heat transfer systems controlled by interfacial phenomena under micro-gravity conditions are not well understood. As a result, the authors proposed the experimental and theoretical study of the Constrained Vapor Bubble (CVB). It is a flight development project. Results obtained on the ISS under micro-gravity conditions will be compared with round-based results obtained at Rensselaer. The dimensions of the passive CVB heat exchangers were optimized for use under micro-gravity conditions where enhanced heat transfer should be achieved. The unique CVB system allows multi-faceted research: 1) it is a basic scientific study in interfacial phenomena, microgravity fluid physics and thermodynamics; 2) it is a basic study in thermal transport; and 3) it is a study of a very effective passive heat exchanger. The results will be used to design passive heat exchangers, which are needed for space exploration.

Ground-based research and development work to support our flight experiment on the International Space Station was proposed for the five-year period starting April 22, 2000. Assistance with the development work for the flight experiment itself at the NASA Glenn Research Center (and the external contractor Northrop-Grumman/ Zin-Tech) along with necessary basic ground-based research and post flight analyses of the data were envisioned. The proposed work was needed to accomplish the science requirements and test matrix outlined in our revised Science Requirements Document (60055-DOC-000) dated October 1999, and to extend the fundamental understanding of transport processes controlled by interfacial phenomena. The latest revision (F) of the SRD is dated July 4, 2004. We are working with a NASA Projects Team headed by Sue Motil at the NASA Glenn Research Center on the design of a microgravity experimental system for the International Space Station. It is anticipated that the flight experiment will be flown in the Fluids Integrated Rack, FIR, using the Light Microscope Module, LMM, on the International Space Station in the Year 2006. Low capillary pressure systems for high heat fluxes are being emphasized. NASA Glenn has extended our current grant under NNC05GA27G.

### **3. ACCOMPLISHMENTS**

Section titles/numbers in the original proposal (III instead of 3) are used below with statements concerning the status of the results.

#### **III A. Assistance to the development work for the flight experiment at the NASA Glenn Research Center.**

Development work on the equipment for the flight experiment is being done at Northrop-Grumman (now Zin-Tech). John Eustace is the CVB lead at Northrop-Grumman (Zin-Tech) for the design and development of the CVBHX cell, which will fit into a slot on the Light Microscope Module, LMM, in the FIR on the ISS. We work as consultants on this part of the project to insure that the final experimental results obtained under microgravity conditions can be compared with those obtained in our ground-based laboratory at Rensselaer. The Critical Design Review for the LMM was held December 10-11, 2003.

#### **III B. Basic ground-based research.**

III B1. Develop a more accurate and efficient algorithm to analyze the flight and ground-based data on curvature.

A considerable amount of new progress was made during the past years on the objective of this subsection with regard to the measurement and analyses of the pressure (curvature and thickness) gradient field very near the contact line. Details of the results are presented in PU 14, PU 16, PU 17, PU 18, PU 19, PU21 and PU 23 listed below in Section 7. Progress on the geometric model for drops was described in PU 5.

In addition, we have found that radiation losses from the cell will have a significant effect on the temperature and heat flux profiles because glass is opaque to room temperature radiation. This was explored in Dr. Basu's doctoral thesis (T2) and some of the results are published in PU3 and PU 13. These results will be particularly useful in analyzing the flight results because of the absence of natural convective heat transfer under microgravity conditions.

### III B2. Develop the use of a digital camera with higher magnification.

In this case, we need to keep our work consistent with that being done at Northrop-Grumman in their development work for the flight experiments. Therefore, we have received on loan from NASA for evaluation a microscope/camera system similar to the one being used by Northrop-Grumman. In essence, we found that the original magnification used in our initial research was optimum. However, we also found that the use of a general purpose Light Microscope Module will probably lead to some compromises with regard to the camera speed. On the other hand, the Northrop-Grumman (Zin-Tech) team is working to optimize the settings (light level, speed, magnification) used in their flight system to minimize adverse effects.

### III B3. Develop improved cleaning and filling techniques.

This work is being done mainly at the Northrop-Grumman (Zin-Tech) facility because they have developed the necessary clean-room facilities to build the CVBHX cells for the flight experiments. We will compare results obtained using one of their (cleaner) final cells in our laboratory with one of our regular test cells. This should be accomplished in the coming year. We are also working with mixtures of alkanes to determine the effect of impurities on the results.

### III B4. Evaluate the regions affected by g-jitter.

We are comparing results obtained in various regions of an oscillating meniscus with results obtained under steady state conditions. In this case, the oscillations are obtained using a change in the heat input. At a sufficiently high heat input, the meniscus becomes unstable and starts to oscillate. Initial results are presented in PU 18 and PU 19 and a more comprehensive paper has recently appeared in the ASME Journal of Heat Transfer, PU23. We find that sufficient data should be obtainable in various regions of the cell with an oscillating meniscus.

### III B5. Evaluate the constant interfacial temperature assumption and its effect on Marangoni flow.

With our pure systems, there does not appear to be significant Marangoni flows. However, to check this observation, we are obtaining results using solutions with various compositions. Results obtained with pure Pentane systems will be compared with results obtained using Pentane mixed with small amounts of Octane. Initial results indicate that the addition of a small amount of a second component leads to a significant change in the thickness profile and therefore the pressure field. However, significant data can still be obtained. In addition, the use of mixtures might be advantageous for the development of enhanced heat exchangers because of enhanced flow due Marangoni effects. These results are currently being analyzed.

### III B6. Do a more rigorous derivation of the fluid flow model.

We have found that a simple control volume model is more useful in describing the experimental results than numerical calculations with more detail obtained using the Navier-Stokes equation. Results are presented in PU 1, PU 2, PU 9, PU 10, PU 17, PU18 and PU 23. However, our experimental data will be extremely useful to other numerical researchers who wish to evaluate their models. Additional new modeling results for axial flow are presented in PU 11.

III B7. Organize and develop procedures to evaluate and compare the effect of the intermolecular force field on the phase change heat transfer process in both wetting and partially wetting systems.

A considerable amount of results concerning this topic are presented in PU 5, PU 6, PU 8, PU 10, PU 12, PU 15, PU 16 and PU 23. Polar and apolar, wetting and partially wetting fluids (alkanes, alcohols, water and fluorocarbons) have been studied. We need to write a review paper to organize our various results.

III B8. Do work on the region where there is condensation.

We have found that the study of the drop-wise condensation process in the CVB is particularly rewarding. Results are presented in PU 1, PU 2, PU 5, PU 6, PU 7, PU 8, PU 10, PU 12, PU 16, PU 17 and PU 21.

III B9. Do research on the two-dimensional curvature field and the three-dimensional temperature field.

Some results are presented in Dr. Basu's thesis (T2). However, the overall project is currently going in the direction of using one-dimensional analyses for fluid flow and heat transfer and a control volume model (PU 1, PU 2, PU 11, PU 17, PU 18, PU 19 and PU 23). We find that it is desirable to initially use this simpler approach to analyze the results because of the large amount of data being obtained. On the other hand, the experimental data will be available for two and three-dimensional analyses in the future. The development of the experimental technique is being emphasized.

III B10. Take data using water as the working fluid.

We find that water is a difficult fluid to use because of the large apparent contact angle associated with the water-glass system. In addition, as is well known, the contact angle is difficult to control. Therefore, we found that we cannot obtain the necessary details of the thickness profile in the contact line region using pure water. However, we have circumvented this problem by using surfactants to lower the apparent contact angle. We have obtained experimental results on these lower contact angle surfactant/water/glass systems, which are being analyzed for publication during the coming year. A portion of Gokhale's thesis (T3) addresses these results.

#### **4. CHANGES IN THE PROPOSED WORK**

Only minor modifications in the direction of the proposed original work have been made, which do not significantly alter our original objective of measuring the enhancement of heat transfer in a low capillary pressure system under microgravity conditions relative to that obtained in the earth's gravitational field. We note that there is one objective that was not explicitly emphasized above but is of general importance in the research: "the development of the use of the Kelvin-Clapeyron model for interfacial phase change heat transfer processes." Significant progress on the development and use of the Kelvin-Clapeyron model, which we anticipate to be of general use, is demonstrated in our publications.

#### **5. PRACTICAL APPLICATIONS.**

The CVBHE being study was designed for optimum performance under micro-gravity conditions. As such, after the advantages of this low capillary pressure system is demonstrated under micro-gravity conditions, we anticipate that designs and applications based on these experimental results will be forthcoming.

## **6. PLANNED WORK FOR NEXT YEAR.**

This contract ended in April of 2005. The current results will be organized further and additional papers written. In addition, an extension (due to the delayed flight experiment) has been funded by NASA under grant # NNC05GA27G. The proposed research is given in the proposal for the extension.

## **7. PUBLICATIONS AND PRESENTATIONS.**

The following list and numbers are from our monthly progress reports to the Project Scientist at NASA Glenn.

### **PRESENTATIONS [PR]:**

PR 1. Wang, Y- X, Plawsky, J. L., and Wayner, P. C., Jr., "Optical Measurement of Microscale Transport Processes in Dropwise Condensation", United Engineering Foundation Meeting, Banff, Canada, Oct. 15-20, 2000. Published in Proceedings of the International Conference on Heat Transfer and Transport Phenomena in Microscale, pp 253-260, Editor: Gian Piero Celata, Begell House, Inc., New York, New York, 2000.

PR2. Wang, Y- X, Plawsky, J. L., and Wayner, P. C., Jr., "Optical Measurement of Thermally Driven Interfacial Flows" Paper 133f, Annual Meeting of AIChE, Los Angeles, CA, Nov. 12-17, 2000.

PR3. S. Basu, P. C. Wayner, Jr., J. L. Plawsky, "Study of Heat Losses For the Dry Cell Calibration of the Constrained Vapor Bubble Heat Pipe", 35 th National Heat Transfer Conference June, 2001, Anaheim, CA. Paper No. NHTC0111681:

PR4. Wayner, P. C., Jr., "Nucleation, Growth, and Surface Movement of a Condensing Sessile Droplet" The International TRI/Princeton Workshop on Nanocapillarity: Wetting of Heterogeneous Surfaces & Porous Solids, Princeton, NJ June 25-27, 2001

PR5. Wang, Y- X, Zheng, L., Plawsky, J. L., and Wayner, P. C., Jr., "Long Range Intermolecular Forces in Change-of-Phase Heat Transfer", Gordon Research Conference on Gravitational Effects in Physico-Chemical Systems: Interfacial Effects, July 8-13, 2001, New London, NH.

PR6. Plawsky, J. L., Wang, Y- X, Zheng, L., and Wayner, P. C., Jr., "Condensate Removal Mechanisms in a Constrained Vapor Bubble Heat Exchanger", Conference & Exhibit on International Space Station Utilization, Kennedy Space Center, FL, October 15-18, 2001, Paper # AIAA 2001-4957.

PR 7. Ling Zheng, Yingxin Wang, Peter C. Wayner, Jr. Joel L. Plawsky, "Condensate Removal Mechanisms in a Constrained Vapor Bubble Heat Exchanger", Paper # MTP-01-29, Proceedings of the United Engineering Foundation Meeting on "Microgravity Transport

Processes in Fluid, Thermal, Biological and Material Sciences II", September 30-October 5, 2001, Banff, Alberta, Canada.

PR 8. Wayner, P. C., Jr., "Adsorption, Evaporation, Condensation, and Fluid Flow in the Contact Line Region", Third International Symposium on Contact Angle, Wettability, and Adhesion, Providence, RI, May 20-22, 2002.

PR 9. Gokhale, S. J., Plawsky, J. L. and P. C. Wayner, Jr., "Effect of Interfacial Superheat on Liquid Profile and Spreading in Dropwise Condensation" 12th International Conference on Surface Forces, Moscow, Russia, June 29 – July 5, 2002.

PR 10. Wayner, P. C., Jr., "Effect of Interfacial Phenomena on a Condensing Sessile Droplet", The Third International Conference on Transport Phenomena in a Multiphase System, Kielce, Poland, June 24 – 27, 2002.

PR 11. Wayner, P. C., Jr., Plawsky, J. L., Zheng, L., and Wang, Y -X, "Constrained Vapor Bubble Experiment" Sixth Microgravity Fluid Physics and Transport Phenomena Conference, Cleveland, OH, Aug. 14-16, 2002.

PR 12. Gokhale, S. J., Plawsky, J. L. and P. C. Wayner, Jr., "Interfacial Dynamics During Dropwise Condensation and Evaporation," AIChE 2002 Annual Meeting, November 3-8, 2002, Indianapolis, Indiana.

PR 13. Gokhale, S. J., Plawsky, J. L. and P. C. Wayner, Jr., "Microscale Interfacial Phenomena in Dropwise Condensation and Evaporation Processes," 2003 ASME Summer Heat Transfer Conference, July 20 – 23, 2003, Las Vegas, Nevada.

PR 14. Basu, S., Plawsky, J. L. and P. C. Wayner, Jr., "Experimental Study of a Constrained Vapor Bubble Fin Heat Exchanger in the Absence of External Natural Convection", Microgravity Transport Processes in Fluid, Thermal, Biological and Materials Sciences Conference III, September 14-19, 2003, Davos, Switzerland.

PR 15. S. J. Gokhale, S. DasGupta, J. L. Plawsky and P. C. Wayner, Jr., "Experimental Verification of the Pressure Gradient with Phase Change in the Contact Line Region" UK HEAT TRANSFER, 8<sup>th</sup> UK National Heat Transfer Conference, Oxford, England, September 9-10, 2003 Paper # PC 4.

PR 16. S. J. Gokhale, S. DasGupta, J. L. Plawsky and P. C. Wayner, Jr., "Experimental Evaluation of Interfacial Profile and Pressure Variation in a Spreading Drop During Condensation", 2003 AIChE Annual Meeting Extended Abstract # 244d, San Francisco, CA.

PR 17. The following paper was presented at the Conference-Workshop on Strategic Research to Enable NASA's Exploration Mission, June 22-23, 2004, Cleveland, OH. : Constrained Vapor Bubble, Joel L. Plawsky and Peter C. Wayner, Jr.

PR 18. S. S. Panchamgam, S. J. Gokhale, S. DasGupta, J. L. Plawsky and P. C. Wayner, Jr., "A Study of an Oscillating Corner Meniscus with Phase Change Using Image Analyzing Interferometry", Presented at the 2004 ASME Heat Transfer/Fluids Engineering Summer Conference, Charlotte, NC, July 11-15, 2004 and published in the proceedings: # HT-FED2004-56146.

PR 19) Shripad J. Gokhale, Joel L. Plawsky and Peter C. Wayner, Jr.  
"Spreading, Evaporation and Contact Line Dynamics of Surfactant Laden Micro-Drops", 2004  
AIChE Annual Meeting, November 7-12, Austin, TX, Presentation and Abstract # 185a.

PR 20) Shripad J. Gokhale, Joel L. Plawsky and Peter C. Wayner, Jr., "Optical Investigation of  
the Interfacial Phenomena during Coalescence of two Condensing Drops and Shape Evolution of  
the Coalesced Drop" 2004 AIChE Annual Meeting, November 7-12, Austin, TX, Presentation  
and Abstract # 169f.

PR 21) Sashidhar S. Panchamgam, Shripad J. Gokhale, Joel L. Plawsky, Sunando DasGupta, and  
Peter C. Wayner, Jr., "Measurement of the Effect of Disjoining Pressure on Shear in an  
Oscillating Evaporating Contact Line Region," First Joint Meeting of the American Institute of  
Chemical Engineers and the Indian Institute of Chemical Engineers, Mumbai, India, December  
27-30, 2005.

PR 22) Peter C. Wayner, Jr., Invited Institute Lecture: "Reflectivity Based Studies of Interfacial  
Phenomena in Equilibrium and Non-Equilibrium Systems," IIT Karagpur, December 13, 2004.

#### PUBLICATIONS [PU]:

PU1. Wang, Y- X, Plawsky, J. L., and Wayner, P. C., Jr., "Optical Measurement of Microscale  
Transport Processes in Dropwise Condensation", Microscale Thermophysical Engineering, Vol.  
5, #1, pp 55-69, 2001.

PU2. Wang, Y- X, Plawsky, J. L., and Wayner, P. C., Jr., "Optical Measurement of Microscale  
Transport Processes in Dropwise Condensation", United Engineering Foundation Meeting,  
Banff, Canada, Oct. 15-20, 2000. Published in Proceedings of the International Conference on  
Heat Transfer and Transport Phenomena in Microscale, pp 253-260, Editor: Gian Piero Celata,  
Begell House, Inc., New York, New York, 2000.

PU3. S. Basu, P. C. Wayner, Jr., J. L. Plawsky, "Study of Heat Losses For the Dry Cell  
Calibration of the Constrained Vapor Bubble Heat Pipe". 2001 National Heat Transfer  
Conference, June 10 -12, 2001, Anaheim, CA, Paper No. NHTC0111681, ASME, NY, NY.

PU4. P. C. Wayner, Jr., "Interfacial Forces in Enhanced Phase-Change Heat Transfer" Invited  
contribution in Mc-Graw-Hill Yearbook of Science & Technology 2002, pp 156-159, Mc-Graw-  
HILL, New York, NY, 2001.

PU5. L. Zheng, Y. X. Wang, J. L. Plawsky, and P. C. Wayner, Jr. "Effect of Curvature, Contact  
Angle, and Interfacial Subcooling on Contact Line Spreading in a Microdrop in Dropwise  
Condensation" Langmuir, Vol. 18, pp 5170-5177, 2002.

PU 6. Wayner, P. C., Jr., "Nucleation, Growth, and Surface Movement of a Condensing Sessile  
Droplet", Colloids and Surfaces A: Physicochemical and Engineering Aspects, Vol. 206 (2002)  
157-165.

PU 7. Wang, Y- X, Zheng, L., Plawsky, J. L., and Wayner, P. C., Jr., "Optical Evaluation of the  
Effect of Curvature and Apparent Contact Angle in Droplet Condensate Removal", J of Heat  
Transfer, Vol. 124, 2002, 729-738.



- PU 8. Wayner, P. C., Jr., "Effect of Interfacial Phenomena on a Condensing Sessile Droplet", in HEAT 2002, Proceedings of The Third International Conference on Transport Phenomena in a Multiphase Systems, Kielce, Poland, June 24 – 27, 2002, , Editor M E. Poniewski, pp 171- 177.
- PU 9. Ling Zheng, Yingxin Wang, Peter C. Wayner, Jr. Joel L. Plawsky," Condensate Removal Mechanisms in a Constrained Vapor Bubble Heat Exchanger", in "Microgravity Transport Processes in Fluid, Thermal, Biological and Material Sciences", Annals of the New York Academy of Sciences, Vol. 974, Editor S. S. Sadhal, 274-287 (2002).
- PU 10. Gokhale, S. J., Plawsky, J. L. and P. C. Wayner, Jr., "Experimental Investigation of Contact Angle, Curvature, and Contact Line Motion in Dropwise Condensation and Evaporation" Journal of Colloid and Interface Science, Vol. 259, pp 354-366 (2003).
- PU 11. Zheng L., Wang, Y- X, Wayner, P. C., Jr., and , Plawsky, J. L., "Microscale Transport Processes in the Evaporator of a Constrained Vapor Bubble" AIAA Journal of Thermophysics and Heat Transfer, Vol.17, No.2, 2003, pp 166 -173.
- PU 12. Gokhale, S. J., Plawsky, J. L. and P. C. Wayner, Jr., "Effect of interfacial phenomena on dewetting in dropwise condensation" Advances in Colloid and Interface Science, 104, 2003, 175 - 190.
- PU 13. Basu, S., Plawsky, J. L. and P. C. Wayner, Jr. , "Experimental Study of a Constrained Vapor Bubble Fin Heat Exchanger in the Absence of External Natural Convection". Proceedings of the Microgravity Transport Processes in Fluid, Thermal, Biological and Materials Sciences Conference III, September 14-19, 2003, Davos, Switzerland. Paper number ECI: MTP-03-03.
- PU 14. S. J. Gokhale, S. DasGupta, J. L. Plawsky and P. C. Wayner, Jr., "Experimental Verification of the Pressure Gradient with Phase Change in the Contact Line Region" Proceedings of 8<sup>th</sup> UK National Heat Transfer Conference, Oxford, England, September 9-10, 2003, Paper # PC 4.
- PU 15. P. C. Wayner, Jr. , "Adsorption, Evaporation, Condensation, and Fluid Flow in the Contact Line Region", 2003, pp 3-32, in Contact Angle, Wettability, and Adhesion, Vol. 3, Editor K. L. Mittal, VSP BV, The Netherlands.
- PU 16. S. J. Gokhale, S. DasGupta, J. L. Plawsky and P. C. Wayner, Jr., Experimental Evaluation of Interfacial Profile and Pressure Variation in a Spreading Droplet During Condensation", 2003 AIChE Annual Meeting Extended Abstract # 244d, San Francisco, CA.
- PU 17. S. J. Gokhale, J. L. Plawsky, and P. C. Wayner, Jr., S. DasGupta. (New title) "Inferred Pressure Gradient in a condensing sessile droplet based on the measured thickness profile", Physics of Fluids, 16, 2004, 1942-1955.
- PU 18. S. S. Panchamgam, S. J. Gokhale, S. DasGupta, J. L. Plawsky and P. C. Wayner, Jr., "A Study of an Oscillating Corner Meniscus with Phase Change Using Image Analyzing Interferometry", # HT-FED2004-56146, Proceedings of the 2004 ASME Heat Transfer/Fluids Engineering Summer Conference, Charlotte, NC, July 11-15, 2004.
- PU19. L. Zheng, J.L. Plawsky, P. C. Wayner, Jr., S. DasGupta, "stability and Oscillations in an Evaporating Meniscus," Journal of Heat Transfer, 126, 2004, 169-178.

PU 20. P. C. Wayner, Jr., J.L. Plawsky "R & D Work on the Constrained Vapor Bubble System for a Microgravity Experiment", Task Book 2004 and 2004 Annual Report (Prelude) for NAG3-2383 were submitted to Office of Biological and Physical Research, OBPR. (October 2004).

PU 21) [SU 9] S. J. Gokhale, S. DasGupta, J. L. Plawsky, and P. C. Wayner, Jr. , "Reflectivity Based Evaluation of the Coalescence of Two Condensing Drops and Shape Evolution of the Coalesced Drop" Physical Review E, 70, 051610, November 30, 2004[ old title: "Experimental Analysis of the Coalescence of Two Condensing Drops and Shape Evolution of the Coalesced Drop"] submitted to Physical Review Letters. At the advice of Physical Review Letters, the paper was rewritten, expanded, and submitted to Physical Rev E..

PU 22) Sashidhar S. Panchamgam, Shripad J. Gokhale, Joel L. Plawsky, Sunando DasGupta, and Peter C. Wayner, Jr., "Measurement of the Effect of Disjoining Pressure on Shear in an Oscillating Evaporating Contact Line Region," Extended Abstract, First Joint Meeting of the American Institute of Chemical Engineers and the Indian Institute of Chemical Engineers, Mumbai, India, December 27-30, 2005.

PU 23) Sashidhar S. Panchamgam, Shripad J. Gokhale, Sunando DasGupta, Joel L. Plawsky and Peter C. Wayner, Jr., "Experimental Determination of the Effect of Disjoining Pressure on Shear in the Contact Line Region of an Evaporating Thin Film" Journal of Heat Transfer, 127. 231-243, 2005.

#### THESES [T], RELATED STUDENT PROPOSALS [PRO], AND INTERNAL REPORTS [IR]

IR1) S. Panchamgam, S. J. Gokhale, J. L. Plawsky, and P. C. Wayner, Jr., "Report on Properties of Fluids and Glass Surfaces Used in Vertical Constrained Bubble" September 2, 2003.

PRO1)S. Basu, "Experimental and Thermal Modeling of the Constrained Vapor Bubble Wickless Heat Pipe", Ph. D. Dissertation Proposal, Department of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, NY, March, 2001.

PRO2) Shripad Gokhale, "Study of Microscale Interfacial Phenomena in Phase Change Processes", Ph. D. Dissertation Proposal, Department of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, NY, October, 2003.

T1) Wang, Y- X, "A Study of the Vertical Constrained Vapor Bubble" Ph. D. Thesis, Rensselaer Polytechnic Institute, Troy, NY, May, 2001.

T2) Sumita Basu Ph.D. Thesis "Experimental Study and Thermal Modeling of the Constrained Vapor Bubble Heat Pipe Operation in a Convection-Free Environment under the Influence of Gravity" Chemical Engineering Department, Rensselaer Polytechnic Institute, Troy, NY, January, 2002.

T3) Shripad J. Gokhale , "Study of Microscale Interfacial Phenomena During Phase Change Processes : Analysis of Micro-Drop and Thin Films," Ph. D. Thesis, Department of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, Troy, NY, January, 2005.